

Numerical Seismicity Prediction with STAN

award number 01HQGR0008

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program element II

Fault Stress Interactions, Seismotectonics, Strain Measurements, Regional
Modeling

Non-technical summary (<100 words)

Under this grant I developed some flexible and objective models of seismic activity. These models use probability theory to test alternative theories of earthquake generation, mostly based upon the triggering of earthquakes by other earthquakes through the transfer of stresses. Some tests are forecasts, predicting where earthquakes will be most common. Other tests focus on aftershock sequences, which are still not fully understood, in spite of all the detailed observations available. I have found that aftershocks are an accelerated version of background activity, which implies that all earthquakes develop slowly, and that mainshocks mostly do not produce "new" events.

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Abstract

The Stress Transfer and Nucleation (STAN) project has produced several interesting and unexpected scientific results. The most important one of these is probably an observational test of failure time re-mapping, which should be published in BSSA during 2002 or 2003. Aftershock modelers have previously suggested that aftershocks may be re-mapped background seismicity, moved forward in time by the mainshock, but observational tests of this theory have not been available. The STAN project has found that compound aftershock sequences show effects of re-mapping. Models of the influence of the Landers mainshock on the decay of Hector Mine aftershocks support the theory, but the theory doesn't actually improve predictions of Hector aftershock counts when STAN is run as a forecast model. The contradiction between these two results is probably less severe than it seems at first, because STAN predictions favor the simplest model in almost all cases. The penalty for extra parameters in the model is much greater than one would predict using conventional statistical techniques. This suggests that there are instabilities or inaccuracies in these data and models which have not yet been understood. The approximate nature of current stress transfer models is one source of inaccuracy, and another is the earthquake nucleation process. STAN models should develop considerable skill when these processes are better understood. The interim results suggest that the successful model of earthquake nucleation will involve a failure process that accelerates toward failure, so that failure time re-mapping may generate aftershock sequences.

1 Investigations

Stress Transfer and Nucleation

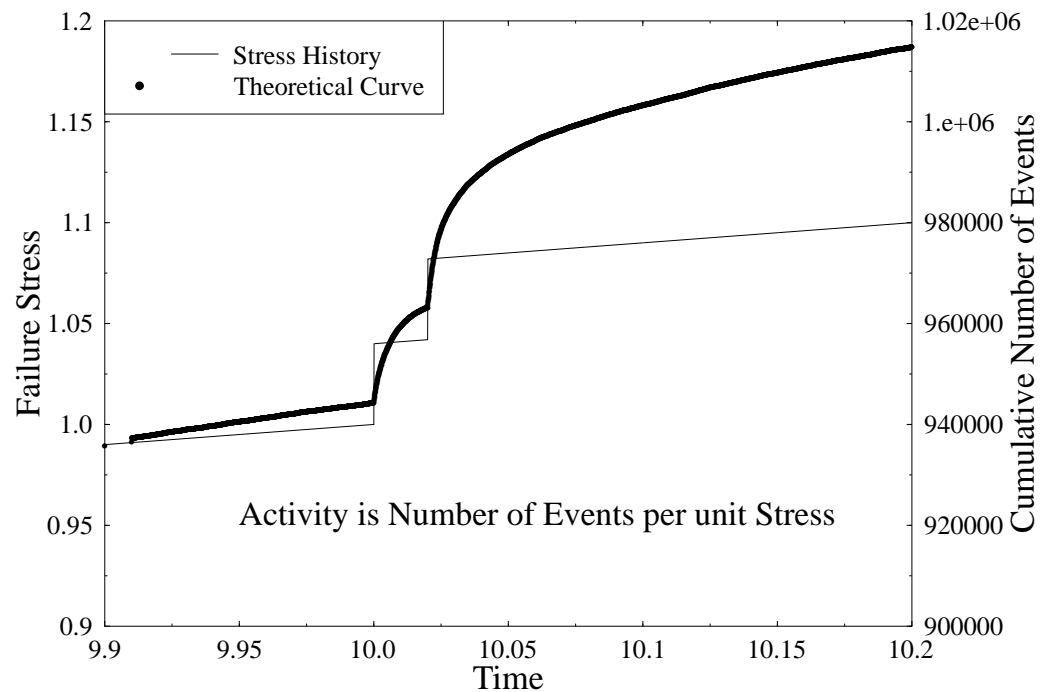
STAN is a new kind of seismicity model which incorporates both spatial and temporal variations in activity, and quantifies how well we understand the earthquake nucleation process. STAN can be used to make formal seismicity rate forecasts, fit models of stress transfer triggering, and invert for tectonic loading patterns given observed seismicity. Although STAN is by no means fully developed, it has already been productive. In implementing STAN, I had to decide what seismicity response was expected when a volume is repeatedly stressed, and developed a new approach to that problem. STAN is constructed with a minimum of free parameters, and it allocates these parameters in proportion to the data, with a clustering algorithm which breaks apart three dimensional space in proportion to the seismic activity. Although STAN can be constructed with any underlying set of assumptions, the current version does not assume that seismicity is concentrated on mapped faults. It instead assumes that the long term spatial seismicity distribution will persist, and be modified by stress transfer from observed mainshocks. The stress transfer generates aftershocks in each volume in proportion to the stress step multiplied by the activity level of that volume. It is assumed that each volume produces background seismicity in proportion to that same intrinsic activity level multiplied by a loading rate. The loading rate can be assumed constant or varied with location. Similarly, STAN can be constructed with a great variety of assumed temporal aftershock decay models.

A Procedural Outline of STAN

1. Cluster events onto an adaptive grid.
2. Compute stress transfer from mainshock sources to each subset.
3. Apply aftershock generation and decay models to each stress subset to compute the "activity" of that location given the observed event count.
4. Evaluate statistical measure of fit for each subset.
5. Optimize, adjusting generation and decay parameters to find best statistic.

A key element of every STAN model is the battery of statistical tests used to evaluate the fit. Since STAN defines an expected seismicity rate as a function of time and space, it is well suited to evaluation with maximum likelihood techniques. Non-parametric Komolgorov-Smirnov (K-S) statistics are also used, because they provide better information about the quality of the fit than likelihood fits do. STAN models can also be evaluated by the quality of their forecasts. Ideally, we would wish that the models have predictive skill, and expect that the best models would make the most successful predictions. After some goodness of fit measure such as the K-S statistic has been optimized, so that the misfit

is minimized, the fit can be re-evaluated for true skill by comparing it with predictions based upon a much simpler algorithm, such as persistence. Tests such as these provide an objective basis for evaluating a huge variety of seismicity models, from exceedingly simple to absurdly complex.



The adaptive grid is created very simply, and has 3 parameters that define it, the minimum and maximum grid size, and the minimum event count. It starts with a very fine grid covering the whole region of interest at a 1km resolution in three dimensions. Those cells that satisfy the minimum event count are kept, and the resolution of the grid is halved for all the others. Then the remaining events are compared with the new grid, and all cells meeting the minimum event count criteria are saved, and the resolution is halved again, until the maximum grid size is reached. Cells of the maximum size do not necessarily satisfy the minimum event count.

2 Results

The STAN model was applied to Landers and Hector mine aftershock sequence subsets, with the results summarized in a table below. The most successful model in this table is Omori with all positive stress steps. This is not true Omori, because it includes a c-value. The best p-value was 1. This is also the simplest model, a pattern that seems to hold for most of the STAN results.

KS statistics of STAN fits			
	Omori	MOM	Dieterich
- Sequential	.291	.291	.334
0 Sequential	.381	.389	.370
+ Sequential	.283	.283	.332

Rank Correlation Prediction Tests

I used rank correlations to evaluate alternative predictions, and tabulated them below. The most successful predictions are made by MOMF, the modified Omori model with fixed background and no variation in p or c-values. The best model computes aftershock abundance assuming stress steps are all positive, and also does not apply the theory of failure time re-mapping discussed below.

Rank Correlations of Hector Aftershock Predictions				
	MOMb	MOMB	STREXPb	MOMF
- Sequential	.406	.390	.410	.391
- Re-mapped	.350	.329	.344	.359
0 Sequential	.417	.398	.416	.401
0 Re-mapped	.346	.329	.334	.349
+ Sequential	.582	.611	.584	.641
+ Re-mapped	.526	.491	.509	.621

3 Non-technical summary (<100 words)

Under this grant I developed some flexible and objective models of seismic activity. These models use probability theory to test alternative theories of earthquake generation, mostly based upon the triggering of earthquakes by other earthquakes through the transfer of stresses. Some tests are forecasts, predicting where earthquakes will be most common. Other tests focus on aftershock sequences, which are still not fully understood, in spite of all the detailed observations available. I have found that aftershocks are an accelerated version of background activity, which implies that all earthquakes develop slowly, and that mainshocks mostly do not produce "new" events.

4 Reports published

- Gross, S. J., Failure Time Remapping in Compound Aftershock Sequences, *submitted to Bull. Seism. Soc. Am.*, 2002.
- Gross, S. J., A model of tectonic stress state and rate using Northridge aftershocks, *Bull. Seism. Soc. Am.*, **91**, 263-275, 2001.

5 Availability of data

The research did not involve the collection of any new data, only the construction of models, so this topic does not apply. Colleagues interested in conducting research with these models should contact Susanna Gross at (303) 492-1039 or sgj@colorado.edu,

Bibliography

- Gross, S. J., Failure Time Remapping in Compound Aftershock Sequences, *submitted to Bull. Seism. Soc. Am.*, 2002.
- Gross, S. J., A model of tectonic stress state and rate using Northridge aftershocks, *Bull. Seism. Soc. Am.*, **91**, 263-275, 2001.
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- Gross, S., Implications of secondary aftershocks for failure processes, Fall AGU, San Francisco, CA, USA, contributed poster, 2001.